Construction Experience with CRC Pavements in Illinois

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16. Abstract

Developing mechanical means for economically setting steel reinforcing in a continuously reinforced concrete (CRC) pavement was one objective of a study Illinois started in 1960. While constructing six experimental pavements between 1963 and 1966, one bar assembly machine and several reinforcement depressors were developed; however, slipform pavers that feed the longitudinal bars through a series of tubes, eliminating the use of transverse bars, have replaced the use of side forms, and now is the most common way of placing CRC pavement in Illinois. Experience indicates that CRC pavement must be built more carefully than conventional jointed pavements; otherwise, insufficient lap and gaps in reinforcement as well as unconsolidated concrete around the reinforcing steel, particularly at joints, will cause early failures. To repair a CRC pavement successfully, patches should be at least 10 feet long by one lane wide, 18 inches from transverse cracks, and 10 feet from construction joints; reinforcing steel exposed for lapping should not be bent above the pavement surface; new steel should be supported on chairs at the same level as the existing steel and should be securely tied; and damaged steel within the lap area, when less than 10 percent, may be repaired by welding; otherwise, welding is not permitted.

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DEPARTMENT OF TRANSPORTATION
Division of Highways
Bureau of Materials and Physical Research

CONSTRUCTION EXPERIENCE WITH CRC PAVEMENTS IN ILLINOIS

by

Jagat S. Dhamrait, Floyd K. Jacobsen and
Philip G. Dierstein

Interim Report

IHR-36

Continuously Reinforced Concrete Pavement

A Research Project Conducted by
Illinois Department of Transportation
in cooperation with
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Federal Highway Administration

March 1977

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INTRODUCTION

In 1960 the Illinois Division of Highways began a comprehensive study of continuously reinforced concrete (CRC) pavement. One of the prime objectives of the research was to promote mechanized construction procedures for reducing the initial cost of CRC pavement while gaining experience in constructing this type of pavement. To achieve this objective, plans were made for constructing experimental pavements in each of the various highway districts.

Although past experience indicated that CRC pavements could be designed to provide long life and economical service, acceptance of CRC pavement construction had proceeded slowly because of its comparatively high initial cost. The high construction cost associated with the early development of CRC pavements was due greatly to the lack of experience in constructing CRC pavement, accompanied by no satisfactory method of economically placing the steel reinforcement. Placement of the reinforcement by machine offered the best possibility of reducing cost in this respect. Several concepts in the design of machines for placing the steel reinforcement were in existence but awaited further CRC pavement construction for trial and development.

Between 1963 and 1966 the Division, in cooperative with Federal Highway Administration, constructed six CRC pavements as part of the research study IHR-36, "Continuously Reinforced Concrete Pavement." This report describes several procedures developed by the contractors who placed the experimental pavements, reviews some of the pavement failures that commonly occur within one year after the pavement is placed, and documents the construction of the six experimental pavements built as a part of the study. Later reports will explain how the experimental pavements have behaved as related to the various design variables.

To reduce the cost of CRC pavement, contractors who were awarded contracts for the experimental pavements were encouraged to develop mechanized procedures for placing CRC pavement. Although they did develop several unique methods for placing steel reinforcement in pavements placed with side forms, equipment manufacturers at the same time were developing a slipform paver which has now become the most popular and efficient method of placing rigid pavement in Illinois. In fact, the use of slipform pavers has helped to slow down rising paving costs in Illinois.

Another benefit in building the experimental pavements was that both contractors and engineers learned the need for following certain paving procedures more meticulously when placing CRC pavement than when placing conventional portland cement concrete (CRC) pavement. Early pavement failures usually were associated with:

Insufficient or no lap of steel reinforcement.

Unconsolidated concrete around steel reinforcement, particularly at construction joints where paving begins.

Improper positioning of steel within slab.

As contractors and engineers gained experience in placing CRC pavement the number of these failures that first occurred has diminished greatly.

This study not only has provided an occasion to obtain valuable construction experience in the several districts but also will provide an opportunity to evaluate certain design factors relative to pavement behavior under a variety of traffic and environmental conditions. The design variables incorporated into the experimental pavements in this study are:

Pavement thickness, 7 inches and 8 inches.

Depth of reinforcement 2 inches, 3 inches, and center of slab.

Type of reinforcement, deformed bars and deformed wire fabric.

Of the six experimental projects, one containing most of the variables was instrumented for intensive study. The other five having only one or two variables were constructed as observation pavements involving only routine observations, measurements, and tests. The instrumented pavement under intensive study is located near Springfield in District 6. This project contains two replicate test sections for each design variable but does not include a control test section. Each test section at the Springfield site is approximately 0.23 miles long. The other five observation pavements range from 3.5 to 6.0 miles long, and one or more of the design features such as pavement thickness, type of reinforcement, or depth of reinforcement is varied among the projects. Also, they have a section of conventional jointed pavement which serves as a control for comparing the behavior between the two types of rigid pavement.

Geographic detail, pavement construction, pavement failures, and repairs for the experimental pavements are discussed in detail in the following sections:

GEOGRAPHIC DETAILS

Site Locations

The geographical location of each project is shown in Figure 1, and a listing of the six projects with corresponding experimental features is given in Table 1. Except for the instrumented pavement (Project 4) in District 6, a control section of conventional jointed 10-inch reinforced portland cement concrete was constructed parallel to or adjacent to the experimental pavement for behavior comparisons.

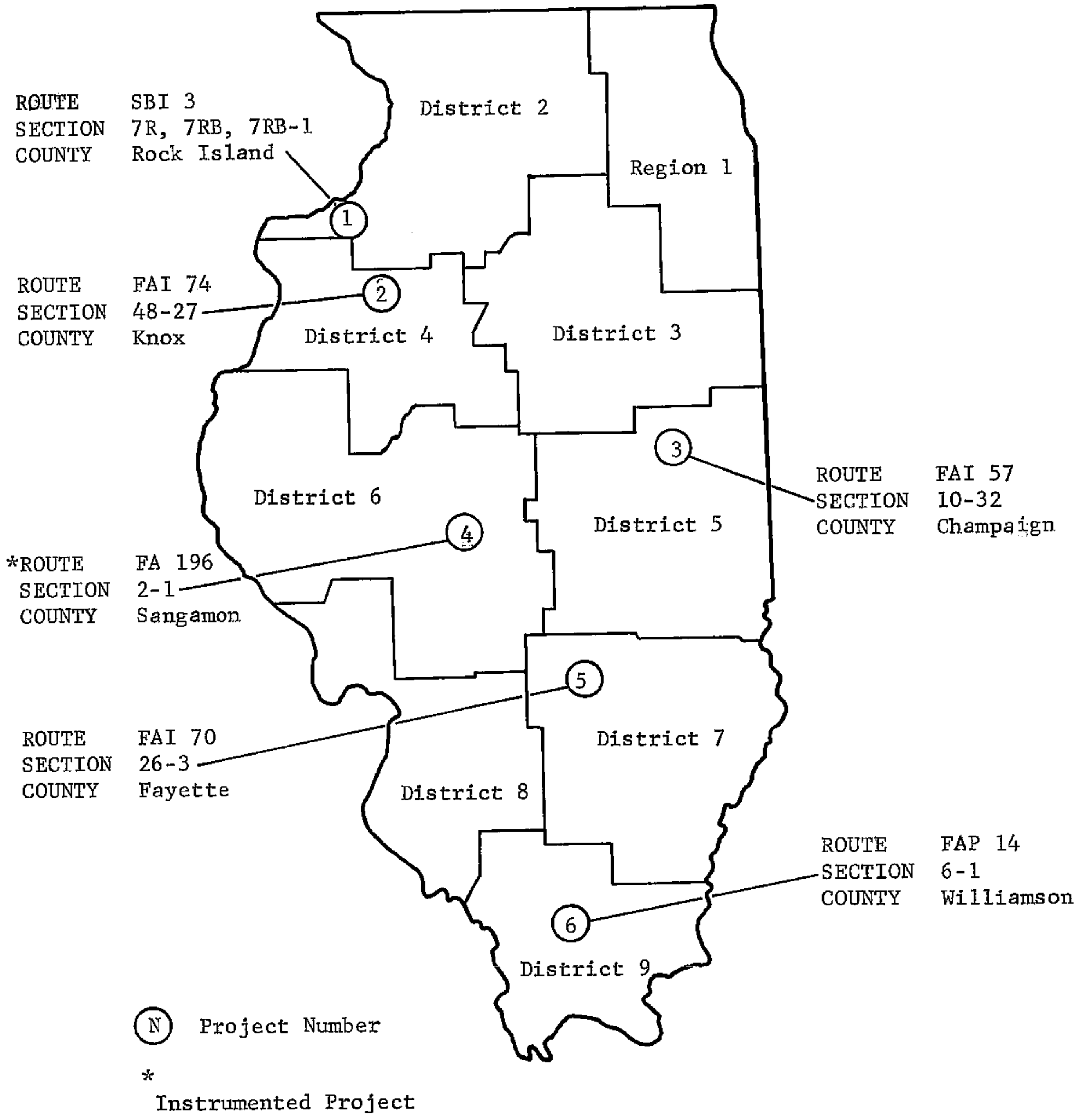


Figure 1. Map showing the location of experimental projects.

TABLE 1

DESIGN FEATURES OF EXPERIMENTAL PROJECTS

Project No.	Route	Section	County	Year Built	Experimental Features: Test Section (mi.)	Slab Thickness (in.)	Reinforcement: Type	Depth (in.)
1	SBI-3	7R, 7RB	Rock Island	1964	2.21	8	Fabric	2
				1964	0.58	8	Fabric	3
				1964	0.98	8	Fabric	4
2	FAI-74	48-27	Knox	1964	2.04	7	Bars	2
				1963	2.04	7	Bars	3.5
				1963	1.45	7	Fabric	3.5
3	FAI-57	10-32	Champaign	1963	2.01	7	Bars	3.5
				1963	2.01	8	Bars	4.0
4	FA-196	2-1	Sangamon	1966	0.23	7	Bars	2
				1966	0.23	7	Bars	3.5
				1966	0.23	7	Fabric	2
				1966	0.23	7	Fabric	3.5
				1966	0.23	8	Bars	2
				1966	0.23	8	Bars	4
				1966	0.23	8	Fabric	2
				1966	0.23	8	Fabric	4
5	FAI-70	26-3,26-4	Fayette	1963	2.00	8	Bars	2
				1963	2.00	8	Bars	3
				1963	2.00	8	Bars	4
6	FA-14	6-1	Williamson	1964	1.90	7	Fabric	2
				1965	2.09	7	Fabric	3.5

Climate[1/]

The climate of Illinois is temperate, but extreme variations in temperature can be expected from day to day, from month to month, and from year to year.

The mean July and January temperatures for Illinois are shown in Figure 2. In July, the warmest month of the year, the mean monthly temperature varies from 74°F in the northern part of the State to 80°F in the southern part of the State. During January, the coldest month of the year, the mean monthly temperature for northern Illinois is 20°F as compared with 38°F in the southern part of the State.

The average annual frost penetration, which is shown in Figure 3, varies from 30 inches at the northwest corner of the State to 10 inches in the southern part of the State.

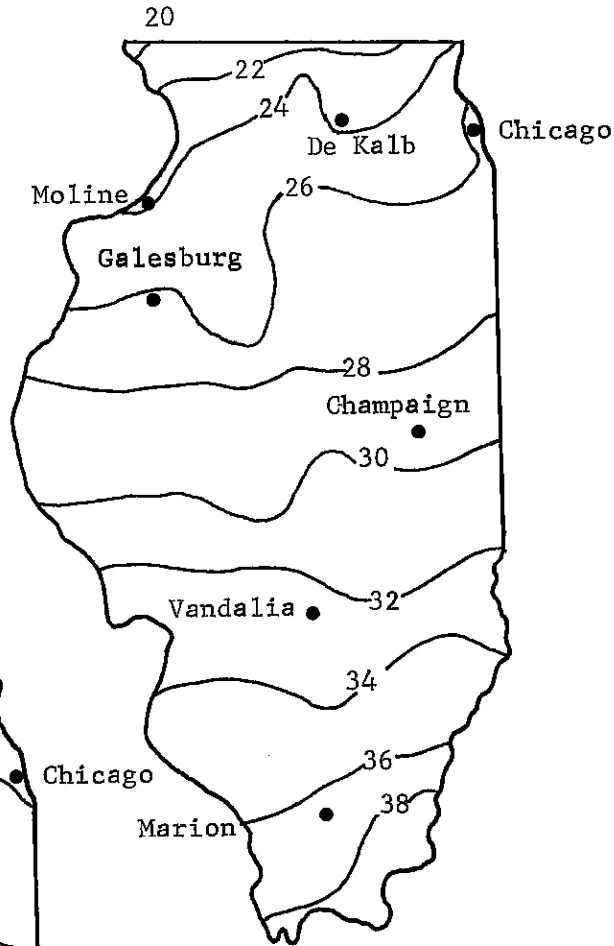
The average annual precipitation varies with location, as shown in Figure 4. The highest average annual precipitation, which occurs in Southern Illinois, is 45 inches, and the lowest average annual rainfall is 32 inches, which occurs in northeastern Illinois.

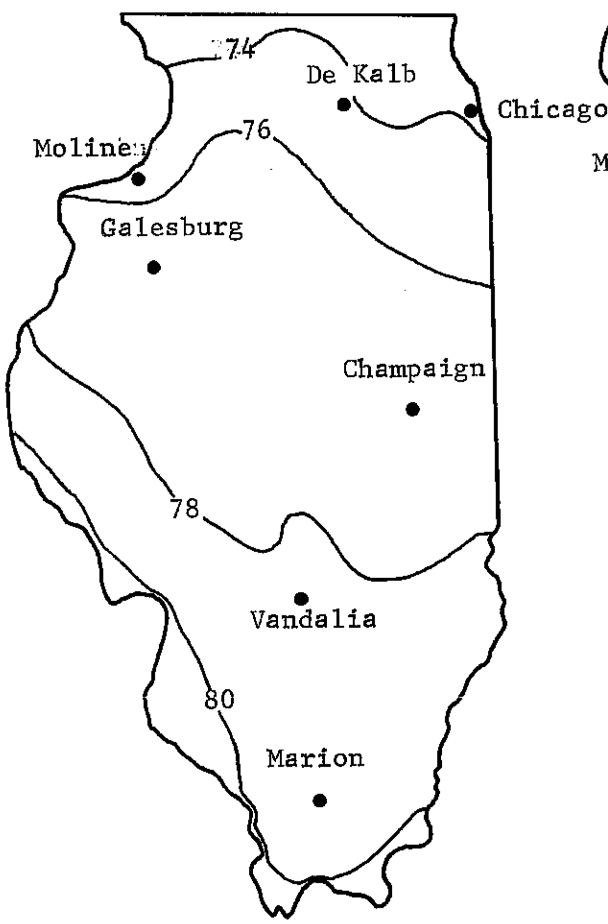
Geology and Soils

"The greater part of Illinois has been glaciated one or more times, and soils are typical of those developed on moraines, till plains, and outwash plains. The northeastern corner of Illinois is possessed of extensive deposits of granular materials. Such materials are not prevalent farther to the south and west. Central Illinois soils are more typically developed on till plains."[2/]

"Subsequent to the glacial age, a mantle of loess covered nearly all of Illinois. The depths of the loess vary from close to 50 feet adjacent to the major river valleys on the western side of the State to depths of such insignificance in some other areas that they may prove difficult if not impossible to

MEAN JANUARY TEMPERATURES





MEAN JULY TEMPERATURES

Figure 2. Mean summer and winter temperatures.

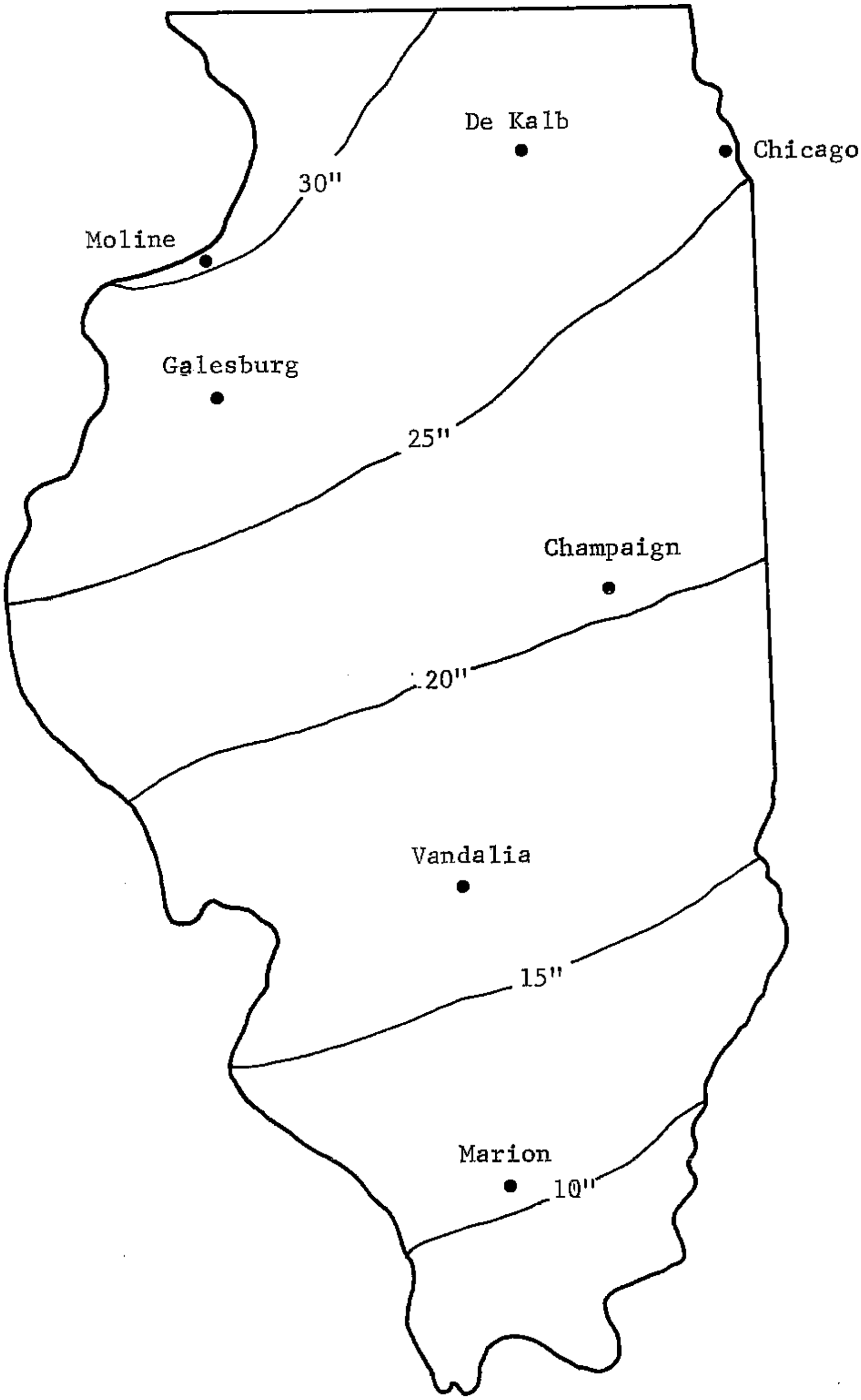


Figure 3. Average annual frost penetration.

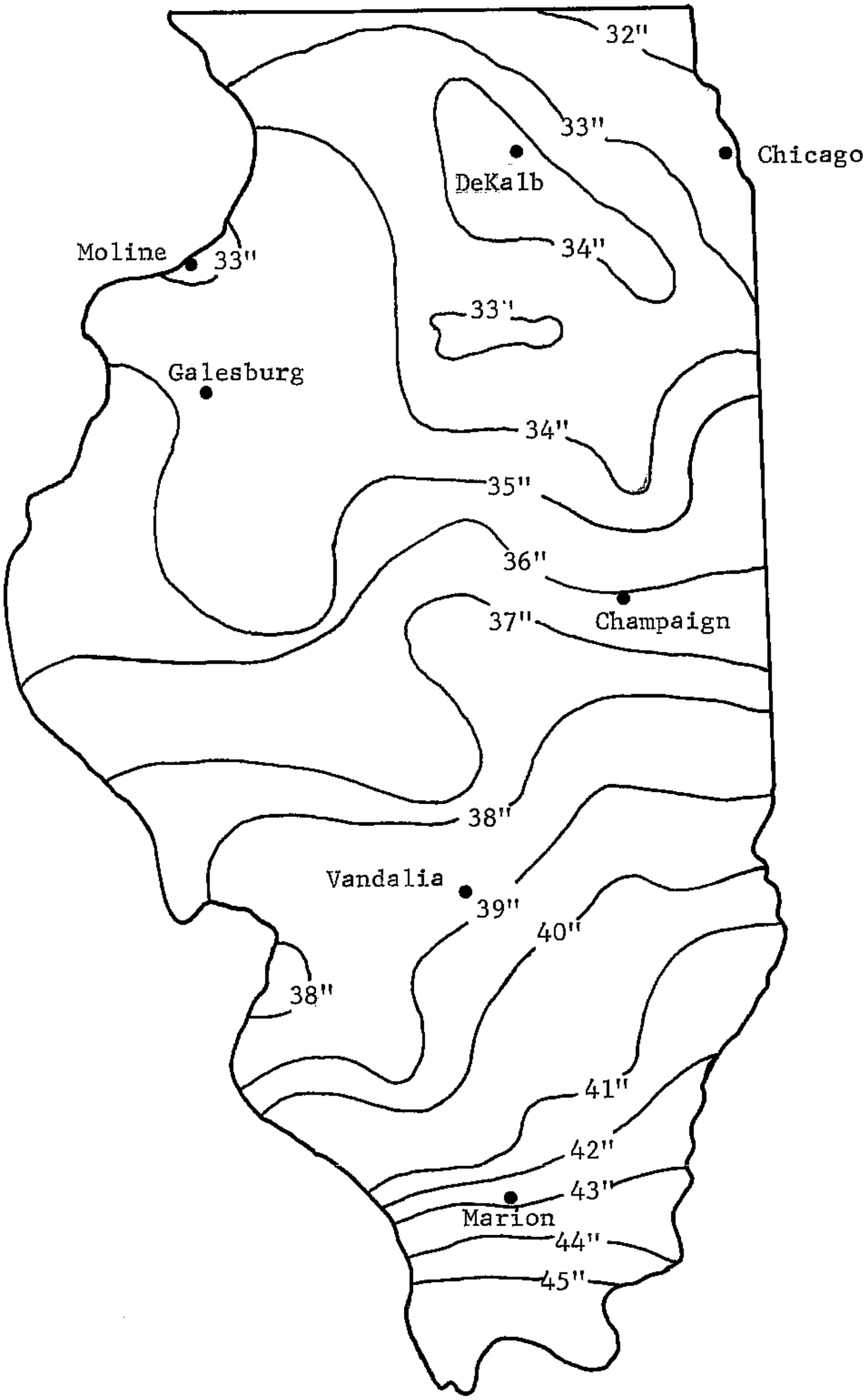


Figure 4. Average annual precipitation.

detect. Many of the morainic deposits are rather complex in character in that there is a complex interbedding of materials of different grain size. These areas frequently necessitate the employment of short cut and fill sections in highway building, and consequent cutting of several different soil types in a relatively short distance. Such conditions usually are associated with the more severe differential frost heaves."[2/]

Sampling and testing of roadbed soils followed the usual procedure for preconstruction soil surveys. On most projects, the samples for field classification were taken from the finished grade at intervals of not more than 300 feet and at locations where the roadbed soil changed in type in both the experimental and the control section. The main soil types found at each project site are summarized in Table 2.

As can be seen in Table 2, samples taken at four of the six projects (2, 4, 5, 6) were mostly clayey (A-6, A-7) soils, but up to one fourth of the samples were classified as silty (A-4) soils. On the other hand, all the soil samples at Project 3 were clayey (A-6, A-7) soils, while those obtained from Project 1 were mostly silty (A-4), yet about one third of the samples were sandy with some traces of gravel.

PAVEMENT CONSTRUCTION

The materials and construction procedures used to build the six experimental CRC pavements conformed to the requirements of Illinois Standard Specifications for Road and Bridge Construction adopted January 2, 1958, to Supplemental Specifications adopted April 2, 1962, and March 2, 1964, that were in effect between 1963 and 1966 when the various contracts were awarded, and to Special Provisions in the Contract Proposals. During paving, a resident observer assigned to each

TABLE 2

CLASSIFICATION OF SOILS
(AASHO Classification)

Project No.	Depth Below Subgrade (ft)	Soil Classification (Percent of Samples)				
		A-1	A-2	A-4	A-6	A-7
1	0-5	8	31	61	-	-
2	0-5	-	-	12	60	28
3	0-3	-	-	-	30	70
4	0-5	-	-	22	61	17
5	0-5	-	-	20	45	35
6	0-5	-	-	25	64	12

project recorded the paving procedures used by the contractor and noted any abnormal details that might help later to explain any unusual behavior in an experimental pavement. More specifically, each observer documented the procedures that the contractor used for installing continuous steel reinforcement in the pavement. In addition to the resident observer, engineers and technicians from other central bureaus and the districts collected data from field tests that would be used later in assessing the behavior of the experimental pavement relative to the design variables. More details about subbase, portland cement concrete surface, reinforcement details, bar and fabric reinforcement depressed mechanically as well as tied in place, curing and joints, all which describe the experimental pavements constructed for this research, follow.

Subbase

The plans called for placing the experimental and the control pavements on a 27-foot granular subbase which extends 18 inches beyond each edge of the pavement. The thickness of the subbase under experimental CRC pavements is 4 inches while that under the control pavement, which is a jointed PCC pavement, is 6 inches.

The Standard Specification for Subbase - Granular Materials, Type A, which is a dense-graded material, allowed the contractor to use either gravel or crushed stone. Specification limits and typical gradations for both gravel and crushed stone are given in Table 3. Gravel was used in Districts 4, 6, and 7 (Projects 2, 4, and 5), while crushed stone was used in Districts 2, 5, and 9 (Projects 1, 3, and 6).

The granular material containing sufficient moisture for compaction was deposited on the subgrade by an approved spreader box in a manner that did not

TABLE 3

GRADATION OF SUBBASE AGGREGATES

	Percent Passing			
	Gravel		Crushed Stone	
Sieve Size	Specification Limits (1)	Typical Gradation	Specification Limits (1)	Typical Gradation
1 in.	100	100	100	100
3/4 in.	80-100	97	-	-
1/2 in.	65-100	86	60-90	84
No. 4	40-60	56	40-60	42
No. 8	25-50	37	25-50	25
No. 16	-	-	20-40	17
No. 40	15-25	18	-	-
No. 200	5-10	8	5-15	7

(1) Standard Specifications for Road and Bridge Construction adopted January 2, 1958.

cause segregation and that required a minimum of blading. Prior to compaction, a sample of subbase material was removed for sieve analysis at intervals not exceeding 1000 feet. Also, density tests were made at the same places after the subbase was compacted. For contracts let after October 1, 1963, the subbase was compacted to not less than 95 percent of maximum dry density (AASHO Designation: T99-57) of the material.

Portland Cement Concrete Surface

The portland cement concrete surface, which was placed directly on the subbase, was produced by mixing cement, sand, and two sizes of coarse aggregate with water and an air-entraining agent. The sources of materials used in each experimental pavement are given in Table 4. The basic concrete mixture for the projects constructed before July 1963 was established in accordance with the Division's "Manual of Instructions for Concrete Proportioning Engineer," effective May 1955, but projects constructed after that time were governed by the manual that became effective July 1963. In both cases the specifications required a mix that produced a workable plastic concrete having a 14-day compressive strength of not less than 3,500 psi, or a minimum modulus of rupture (centerpoint loading) of at least 650 psi at 14 days.

The specifications required that the slump ordinarily shall be not less than 3/4 inch nor more than 1½ inches. Slumps in excess of 1½ inches and up to 3 inches were permitted provided additional cement was added to avoid increasing the water-cement ratio; however, the amount of cement added in no case was less than 0.02 bbls per cu yd of concrete for each ½-inch increase in slump. The batch proportions per cu yd of concrete for each of the projects are given in Table 5, and the aggregate weights are based on a saturated surface dry condition.

TABLE 4

SOURCE OF PCC MATERIALS

Project No.	Cement	Aggregate: Coarse Size A	Aggregate: Coarse Size B	Aggregate: Fine Sand
1	Linwood, Iowa	Milan	Milan	Chillicothe
2	Linwood, Iowa	Chillicothe	Chillicothe	Chillicothe
3	Dundee, Michigan	Fairmont	Fairmont	Mahomet
4	Mitchell, Indiana	Kankakee	Kankakee	Springfield
5	Mitchell, Indiana	Cayuga, Indiana	Cayuga, Indiana	Brownstone
6	Joppa	Chester	Chester	Shawneetown

TABLE 5

PORTLAND CEMENT CONCRETE PROPORTIONS PER CUBIC YARD

Material	Project Number					
	1	2	3	4	5	6
Cement (bags)	5.84	5.68	5.76*	5.84*	5.72	5.76
Sand, lbs. s.s.d.	1075	1083	1064	1086	1103	1143
A Stone, lbs. s.s.d.	908	1041	1025	1011	912	910
B Stone, lbs. s.s.d.	1157	1041	1025	1011	1121	1100
Water, gals.	29.8	29.0	31.1	30.4	27.2	28.8
Air-Entraining Agent, fl. oz.	9.1	4.3	1.4	2.9	8.6	7.0

* Type IA Air-Entraining Cement

Except for Type IA Air-Entraining Cement used in Districts 5 and 6, Type I Portland Cement was used in the concrete for the experimental pavements. The specifications in effect at that time required an air-entrainment of not less than 4 percent nor more than 6 percent of the volume of the concrete. A nominal amount of air-entraining agent was added to the mixes containing Type IA Air-Entraining Cement to meet the specified air content.

Concrete for Projects 2, 3, and 5 was mixed in a paver at the project site and was discharged directly onto the subbase by means of a boom and bucket, but that for Projects 1, 4, and 6 was mixed centrally at a batch plant and was delivered to the project site in agitator trucks.

Reinforcement Details

The experimental pavements were designed with 0.6 percent steel based on the gross cross-sectional area of the pavement, and the steel reinforcement consisted of either deformed bars or cold-drawn deformed wire fabric. When bars were required, the longitudinal steel consisted of No. 5 bars at 7½-inch centers for 7-inch pavements, and No. 5 bars at 6½-inch centers for 8-inch pavements. The transverse reinforcement was No. 3 bars at 25-inch centers for both 7- and 8-inch pavements.

When fabric was required in 7-inch pavements, usually it was composed of longitudinal wires (D-18) at 4-inch centers and transverse wires (D-4) at 12-inch centers. For 8-inch pavements, the fabric consisted of longitudinal wires (D-21) at 4-inch centers and transverse wires (D-5) at 14-inch centers.

The special provisions for each project gave the contractor a choice of three methods for placing the reinforcement in the pavement:

(1) Depressing the reinforcement by mechanical means in the full-depth concrete.

(2) Placing the reinforcement by mechanical means on the lower lift of concrete.

(3) Presetting the reinforcement by hand on chairs which rest on the grade.

Of the three methods allowed, contractors preferred method one and method three over method two. Regardless of the method used, the final position of the steel reinforcement after finishing was specified to be within ½ inch vertically and horizontally of the location shown on the plans.

The lap of the reinforcing bars as shown in Figure 5 was staggered in accordance with one of the following three methods:

(1) Staggering the lap of every third bar at the one-third points of a bar length.

(2) A uniform staggering of all bars within a distance of 10'-6" to 15'-9" in a 12-foot lane of pavement.

(3) Staggering the lap of every other bar but keeping the distance between adjacent laps not less than 3 feet.

A minimum lap of 30 bar diameters was specified for the bar reinforcement. For wire fabric a minimum lap of at least 35 wire diameters was specified, with the lap of individual sheets staggered at 4-foot intervals as shown in Figure 5. The minimum length specified for both bar and fabric was 30 feet.

Bar reinforcement was assembled by fastening longitudinal bars to transverse bars with tie wires, clips, or other acceptable methods meeting the approval of the "Engineer." Except for the outside bars, the longitudinal bars were tied to every other transverse bar, and the ties of adjacent longitudinal bars were staggered. The outside longitudinal bars were tied at every transverse bar.

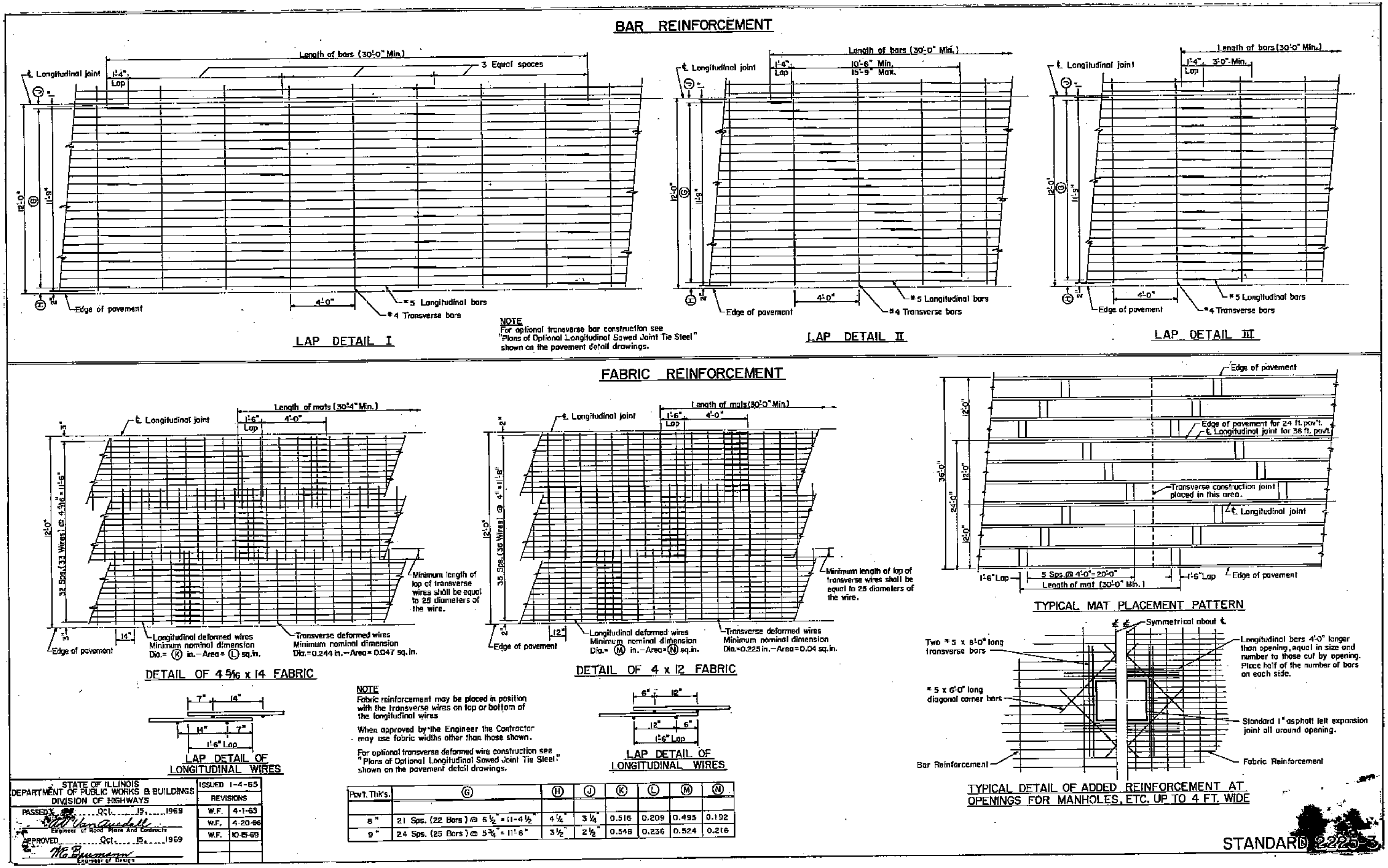


Figure 5. Standard reinforcement details for CRC pavement.

When fabric reinforcement was used instead of bars, laps between sheets of fabric were held firmly by tie wires or clips. However, with permission of the Engineer, ties at laps were omitted when fabric reinforcement was depressed by mechanical means.

Bar Reinforcement Depressed Mechanically

A method of mechanically placing the bar reinforcement in full-depth concrete was developed for paving the experimental section in District 7 (Project 5). The paving train consisted of a concrete spreader, a reinforcement bar assembly machine, a depressor, and a finishing machine, which all traveled on side forms. Both the assembly machine and the depressor are shown in Figure 6. A crew of 16 men was involved in placing the reinforcement.

After placing concrete full depth between the forms, tie bars that extend across the centerline of the pavement beneath the longitudinal bars were embedded into the concrete behind the spreader. The tie bars, which consisted of No. 4 bars, 30 inches long at 30-inch centers, were placed in the notches of two revolving disks by a workman seated at the rear of the spreader. As the spreader advanced, the notched disk rotated and depressed the tie bars into the plastic concrete.

A reinforcement bar assembly machine developed and used by the contractor followed directly behind the spreader. This machine carried a supply of both transverse and longitudinal bars. Transverse No. 3 bars were fed into rotating notched disks by two workmen (Figure 7), who were seated on the machine behind the rotating disks. As the machine moved forward, the notched disks rotated, depressing the transverse bars at 25-inch centers in the full-depth concrete prior to placing the longitudinal reinforcement.

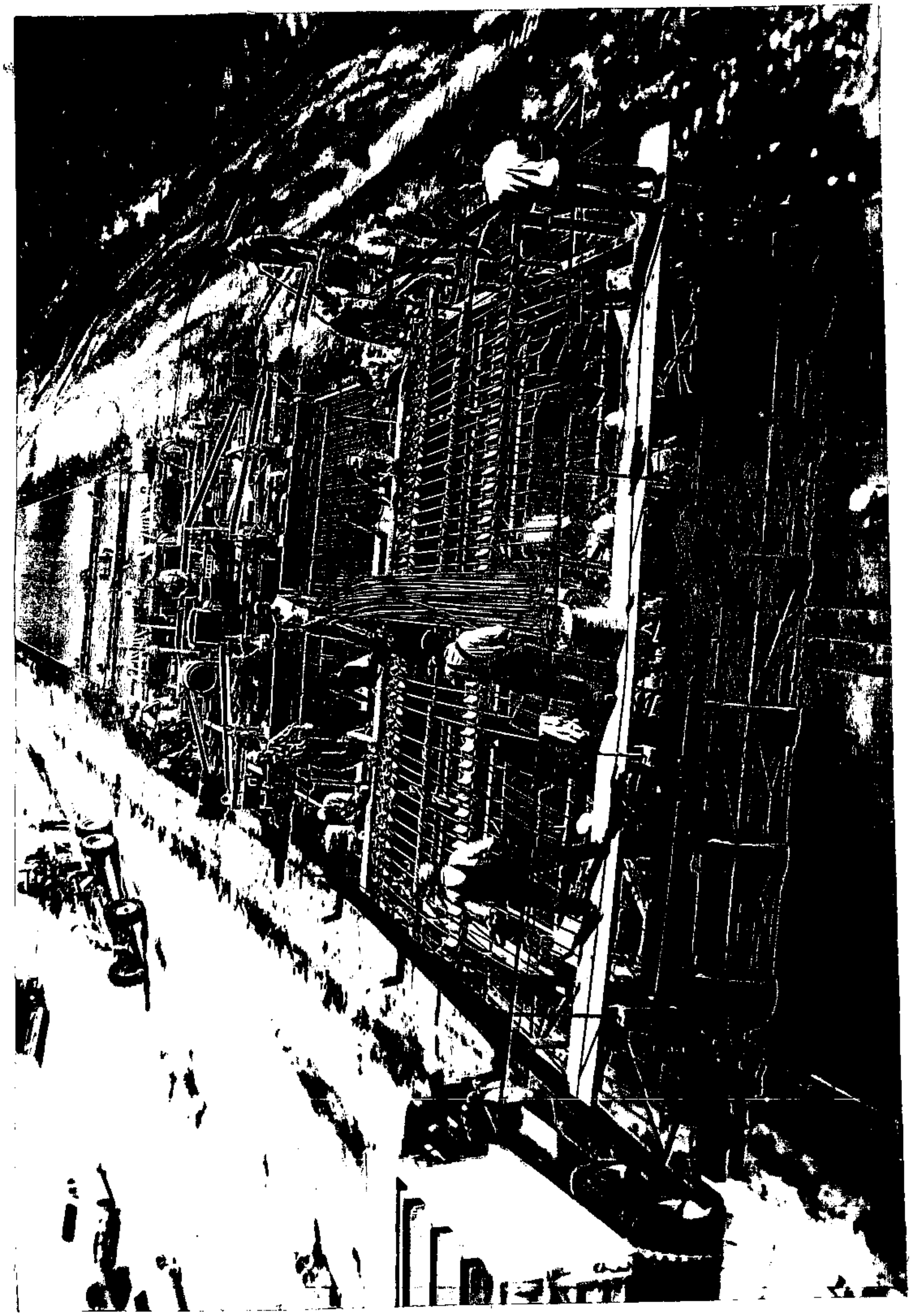


Figure 6. Equipment used for mechanically placing deformed bar reinforcement.

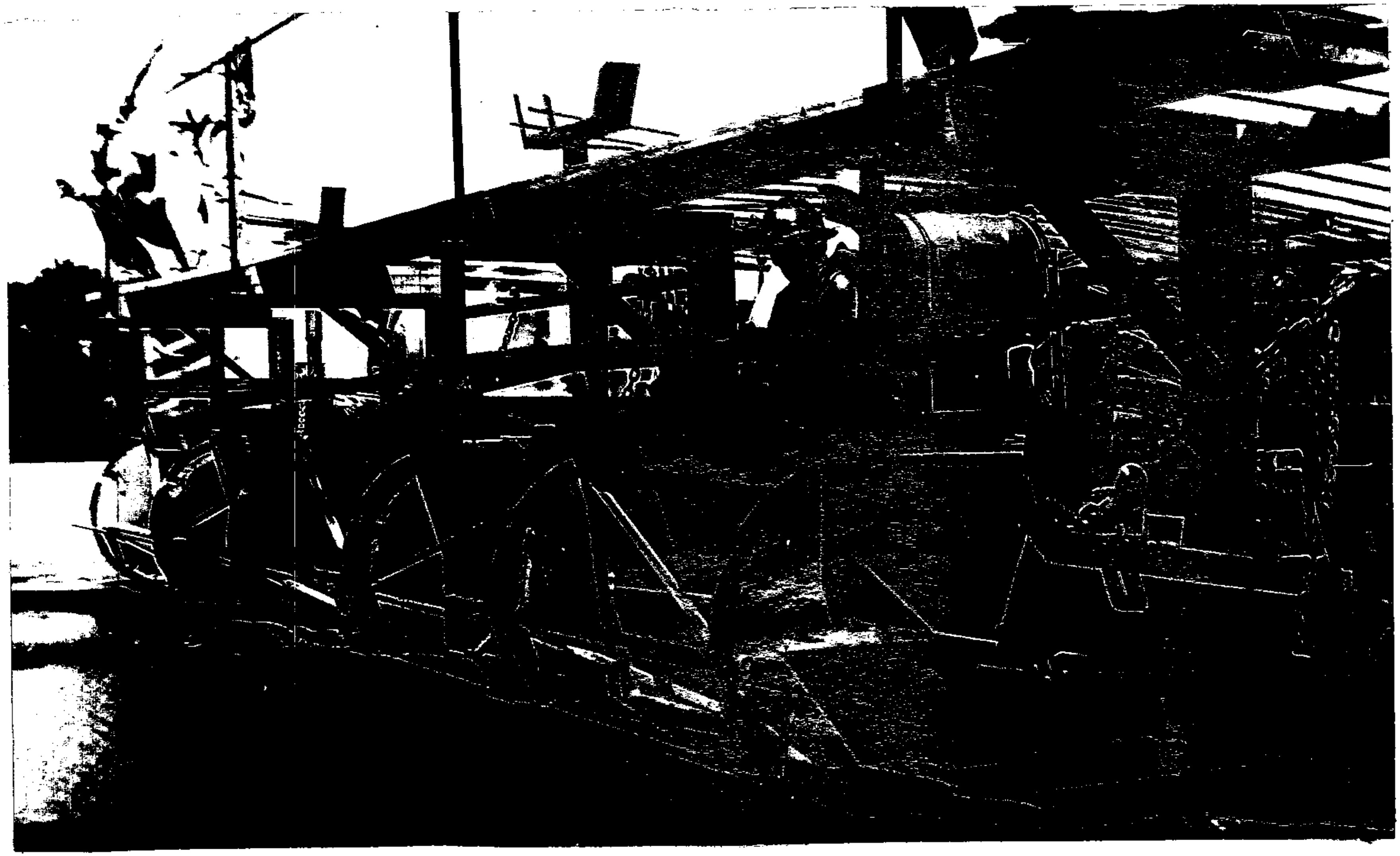


Figure 7. Rotating notched disks for placing the transverse reinforcement.

Longitudinal bars, which were lifted onto storage racks on either side and in the middle of the assembly machine by a crane, were distributed to the placement cradles by six workmen (Figure 8). Three supporting cradles each made from 44 split-pipe sections welded to a transverse member in the machine properly positioned all 44 longitudinal bars. These cradles were painted alternately red and yellow. Using this color code as a guide, the bars were delivered alternately to red and then to yellow cradles, with the lap of alternate bars staggered at 15-foot intervals. Six men, seated at the rear of the machine, tied the lapped bars as the machine moved forward. The tied longitudinal bars were positioned on top of the plastic concrete by passing under grooved rollers at the rear of the assembly machine (Figure 9).

A depressor machine following the assembly machine was used to vibrate and depress the reinforcement down to its specified depth and lateral position into the concrete (Figure 10). As the vibrating frame of the depressor pressed the longitudinal bars in the concrete, the concrete was consolidated around the bars. Then a finishing machine struck off and consolidated the concrete surface to the cross section shown on the plans. The final finish was completed with a burlap drag.

Fabric Reinforcement Depressed Mechanically

The deformed wire fabric reinforcement used in Districts 2, 4, and 9 was placed on the surface of the full-depth concrete by a crew consisting of 4 to 6 men, and was depressed mechanically to a specified depth in the fresh concrete.

The procedure used by the contractor in District 4 (Project 2) for depressing fabric sheets was similar to the procedure described for bars in District 7 (Project 5). Concrete was hauled to the work site in trucks and was placed full

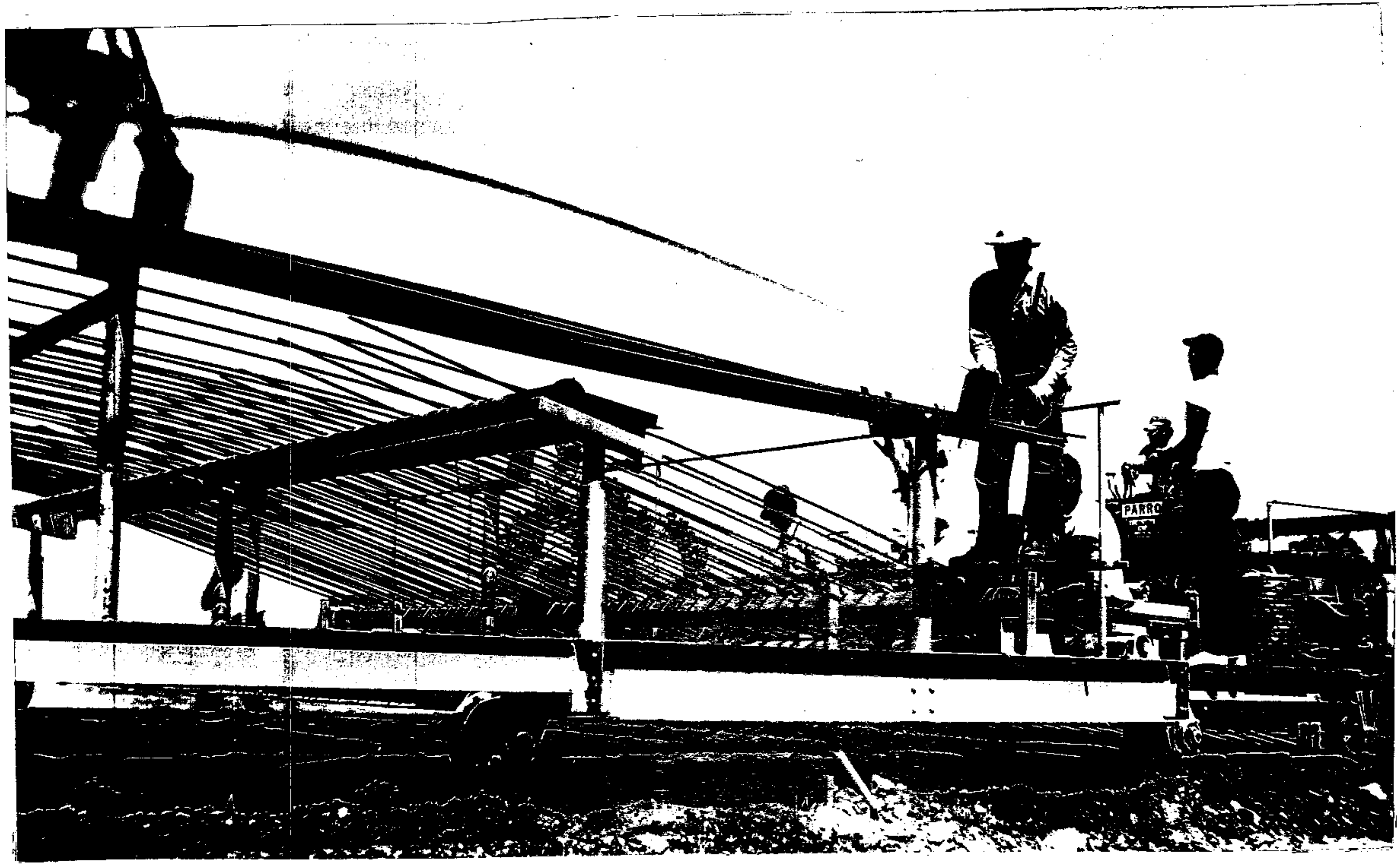


Figure 8. Longitudinal bars being transferred to the placement cradles.

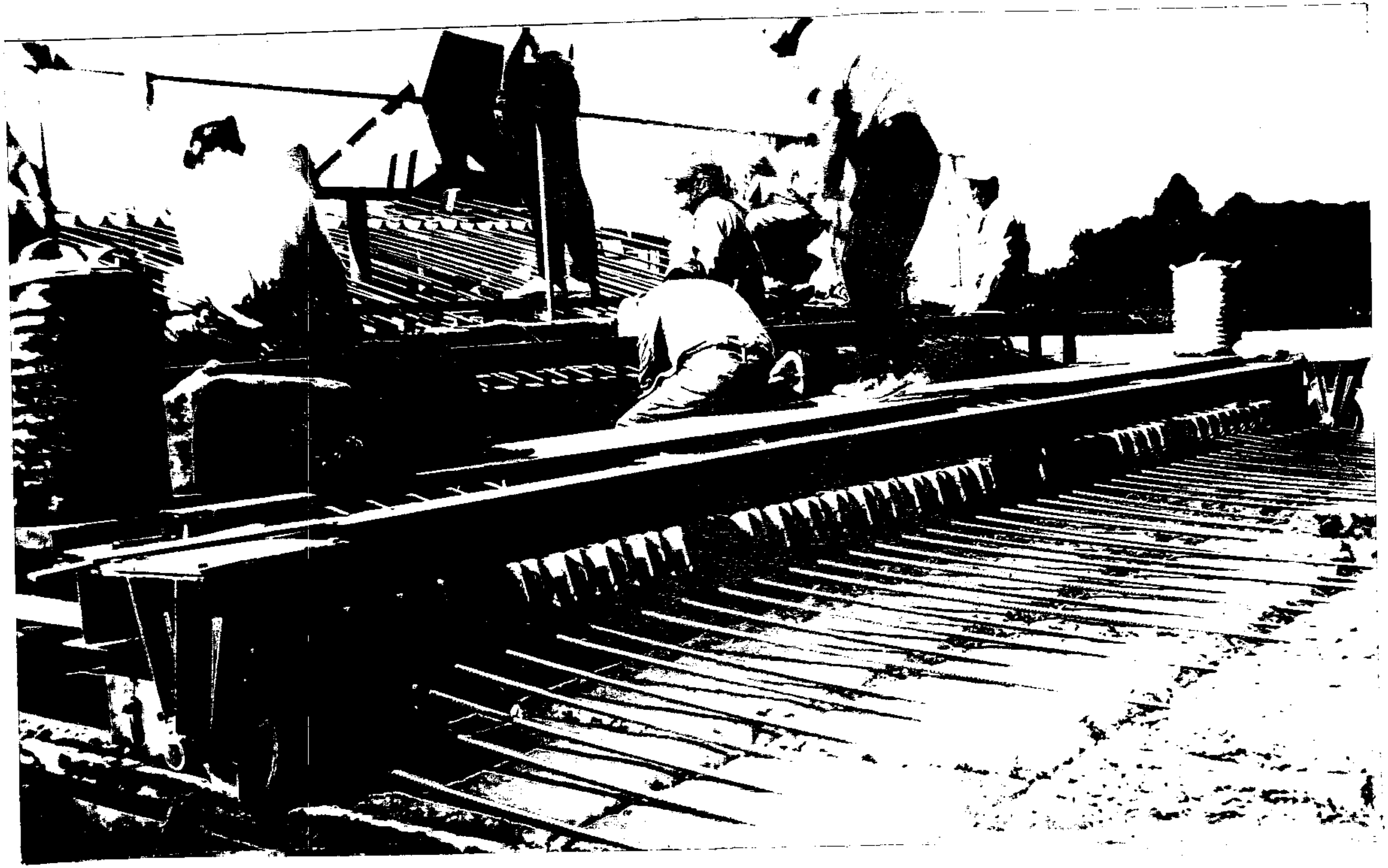


Figure 9. The assembled mat of reinforcement bars being placed on the top of plastic concrete by grooved rollers.

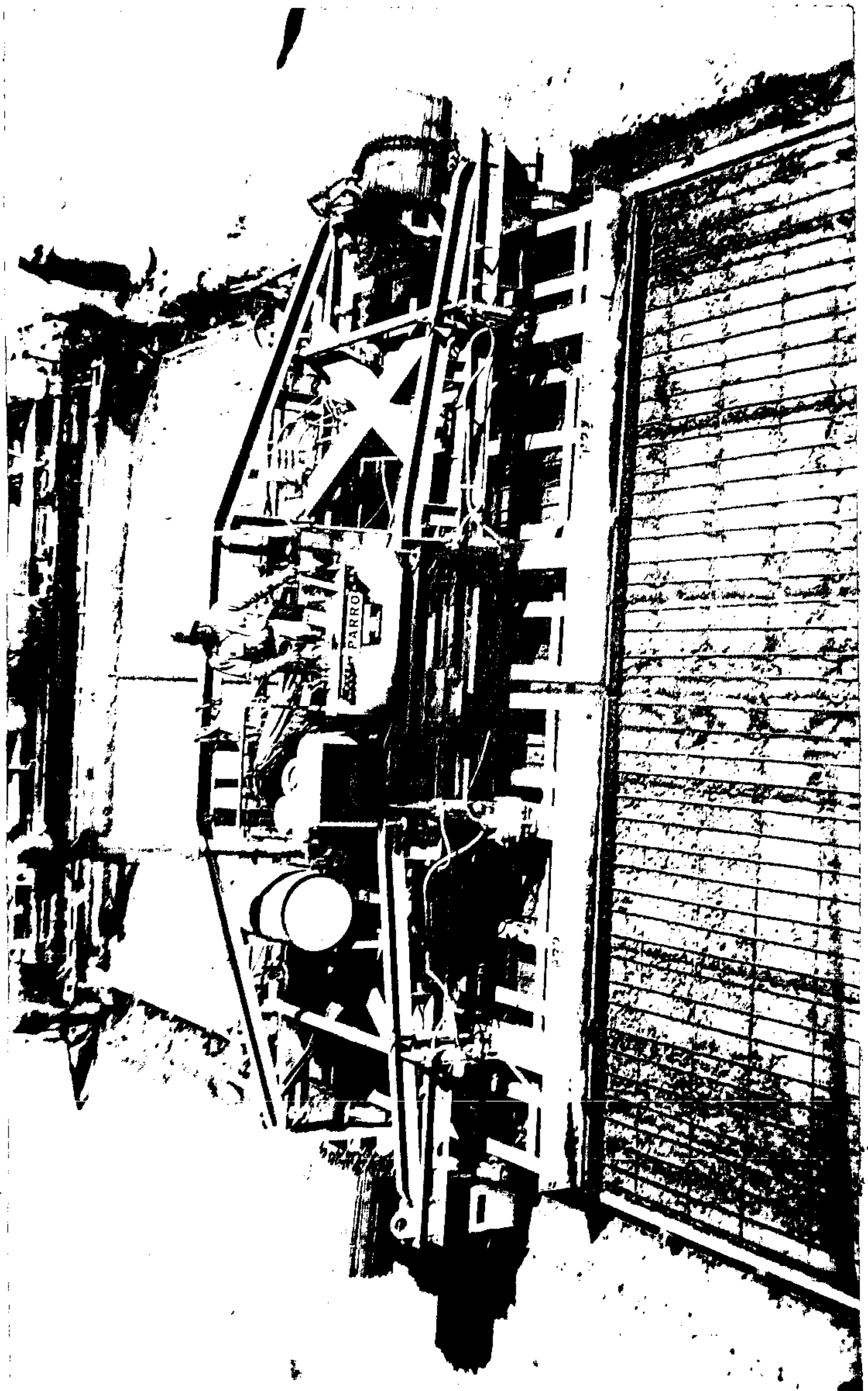


Figure 10. Mechanical Depressor.

depth between the forms with the spreader. As the spreader moved forward, No. 4 tiebars, 30 inches long, were depressed into the concrete at 30-inch centers by a revolving notched disk attached to the rear of the spreader. After the spreader passed, deformed wire fabric was placed by workmen on the plastic concrete surface. As previously mentioned, individual sheets of fabric were staggered at 4-foot intervals so that only one sixth of the pavement cross section is affected by laps at any one place. Then the depressor machine hydraulically depressed the fabric into the concrete to a specified depth. The depressor had four independently operated grids which were 15 feet long and 5½ feet wide (Figure 11). After depressing a part of the reinforcement, the operator moved the machine from 7 to 10 feet ahead, allowing from one half to one third lap of the previously depressed fabric, and depressed the frame again. Then a finishing machine, which followed the depressor, struck off and consolidated the surface to the cross section shown on the plans.

The depressors used in Districts 2 and 9 (Projects 1 and 6) were attached to the front of the finishing machine instead of being a separate machine, and operated on a ski-shaped sled principle (Figure 12). As the finishing machine moved forward, the sleds vibrated and pressed the steel fabric into the concrete to a specified depth. When the specified depth of reinforcement changed, the vertical position of the sleds was adjusted to the new level. As the fabric was being depressed, the finishing machine to which the depressor is attached struck off and consolidated the surface to the section shown on the plans. A burlap drag was used to give the pavement a textured finish.

Reinforcement Tied In Place

Longitudinal deformed bars placed by hand on chairs was the method contractors used to place reinforcement in Districts 4, 5, and 6 (Projects 2, 3, and 4). One

Figure 11. Mechanical depressor with four independent hydraulic grids.

Figure 12. Mechanical depressor attached to finishing machine.

of several manufactured transverse bar chair assemblies, which had previously been approved, was selected by the contractor to support the longitudinal bars. The transverse reinforcement consisted of No. 3 bars spaced at 25-inch centers to reduce excessive deflection and displacement of the longitudinal bars when placing and finishing the concrete pavement. The transverse and longitudinal bars were tied together at alternate intersections (every 50 inches), using either tie wires or wire clips spotwelded to the transverse bars (Figure 13). The specifications required that sand plates be welded to the bottom of chairs to maintain support of the reinforcement at its specified depth. Chairs with sand plates were placed under alternate transverse bars. On some projects the ends of transverse bars were color coded to insure their correct placement.

The current standard calls for transverse No. 4 bars at 48-inch centers with wire clips used to attach the longitudinal bars to the transverse bars at every intersection.

The reinforcement across the longitudinal center joint, which usually consisted of No. 4 tiebars, 30 inches long, at 30-inch centers, was placed in one of two ways, depending on the depth of the reinforcement. When the longitudinal reinforcement was above mid-depth, the tie bars were tied underneath the longitudinal reinforcement, but when the reinforcement was at mid-depth, the tie bars were positioned in the concrete with the notched disk previously described. In later projects with the approval of the Engineer, tie bars were omitted, but in these cases alternate transverse bars spaced at 48-inch centers were extended across the longitudinal center joint in their place. This arrangement provided ties across the joint at 24-inch centers. This method proved to be satisfactory and was adopted as an alternate method of providing ties across longitudinal center joints.

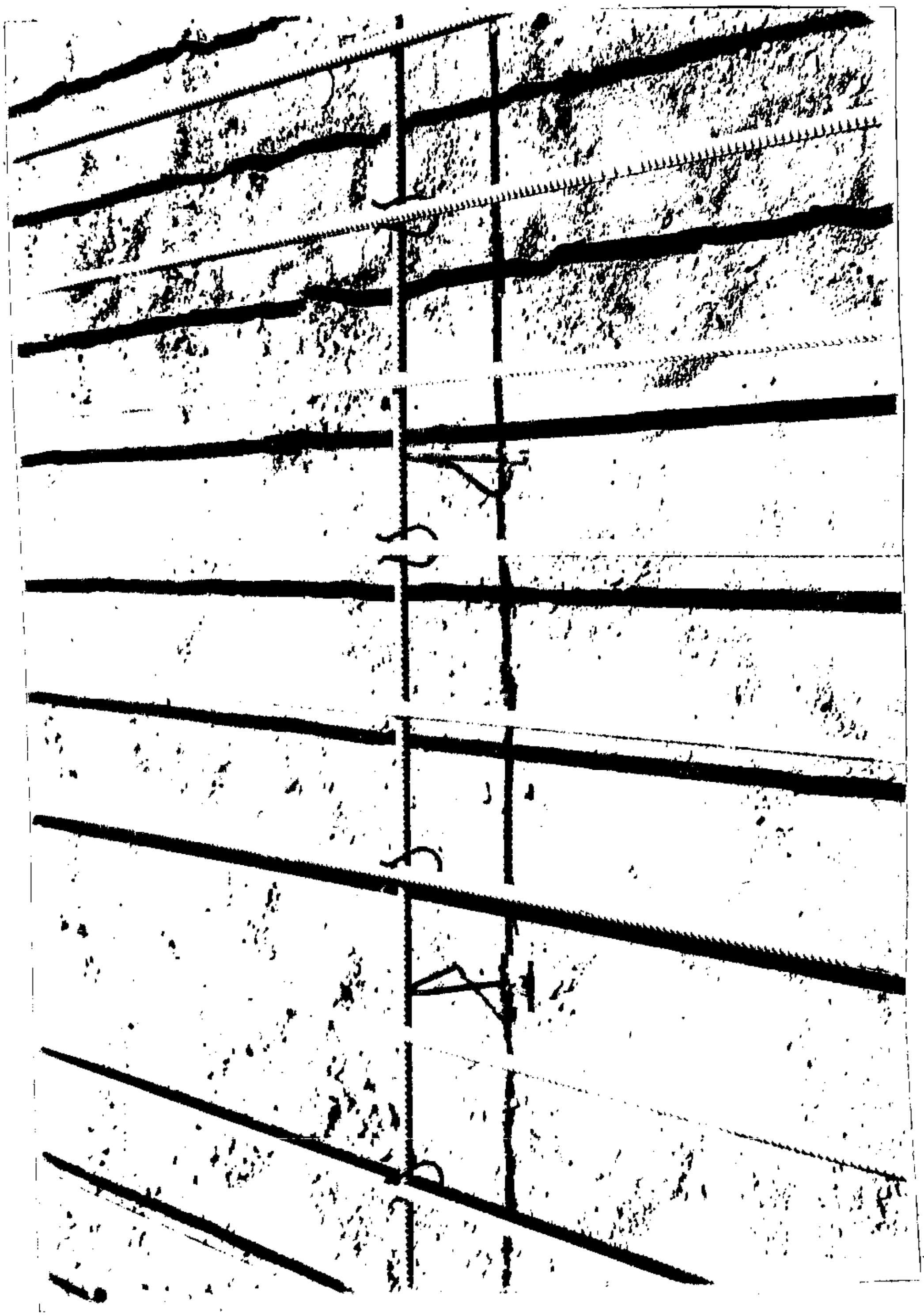


Figure 13. Chair assembly with clips.

Curing

"The hardening and strength gain of concrete is dependent on the availability of moisture and the maintenance of suitable temperature for the hydration processes. The durability and long-term utility of the pavement are greatly dependent on the timely use of adequate curing methods."[3/] The experimental pavements were cured by covering them as soon as possible with polyethylene sheets. On hot and windy days, it was necessary to spray a mist of water on the pavement immediately ahead of laying the polyethylene sheets. The specification required the pavement to remain covered for at least 72 hours. Since most CRC pavement in Illinois today is being placed by slipform pavers, the specifications now allow the contractor to seal the surface with a membrane curing compound. Two separate applications, applied at least one minute apart, each at the rate of not less than one gal to an area of 250 sq ft, are required upon the surfaces and edges of the concrete.

Joints

Although one of the main features of continuously reinforced pavement is the elimination of transverse joints, construction joints are unavoidable at the end of a day's work or at a place where paving is interrupted for more than 30 minutes. The specifications require that the distance from the construction joint to the nearest bar lap shall be at least 3½ feet.

Normally, transverse construction joints were formed by unoiled split-header boards conforming to the cross section of the pavement (Figures 14 and 15). Because the face of the construction joint is smooth, in contrast to the aggregate interlock found at natural transverse cracks, it is necessary to increase the amount of longitudinal reinforcement at construction joints to provide

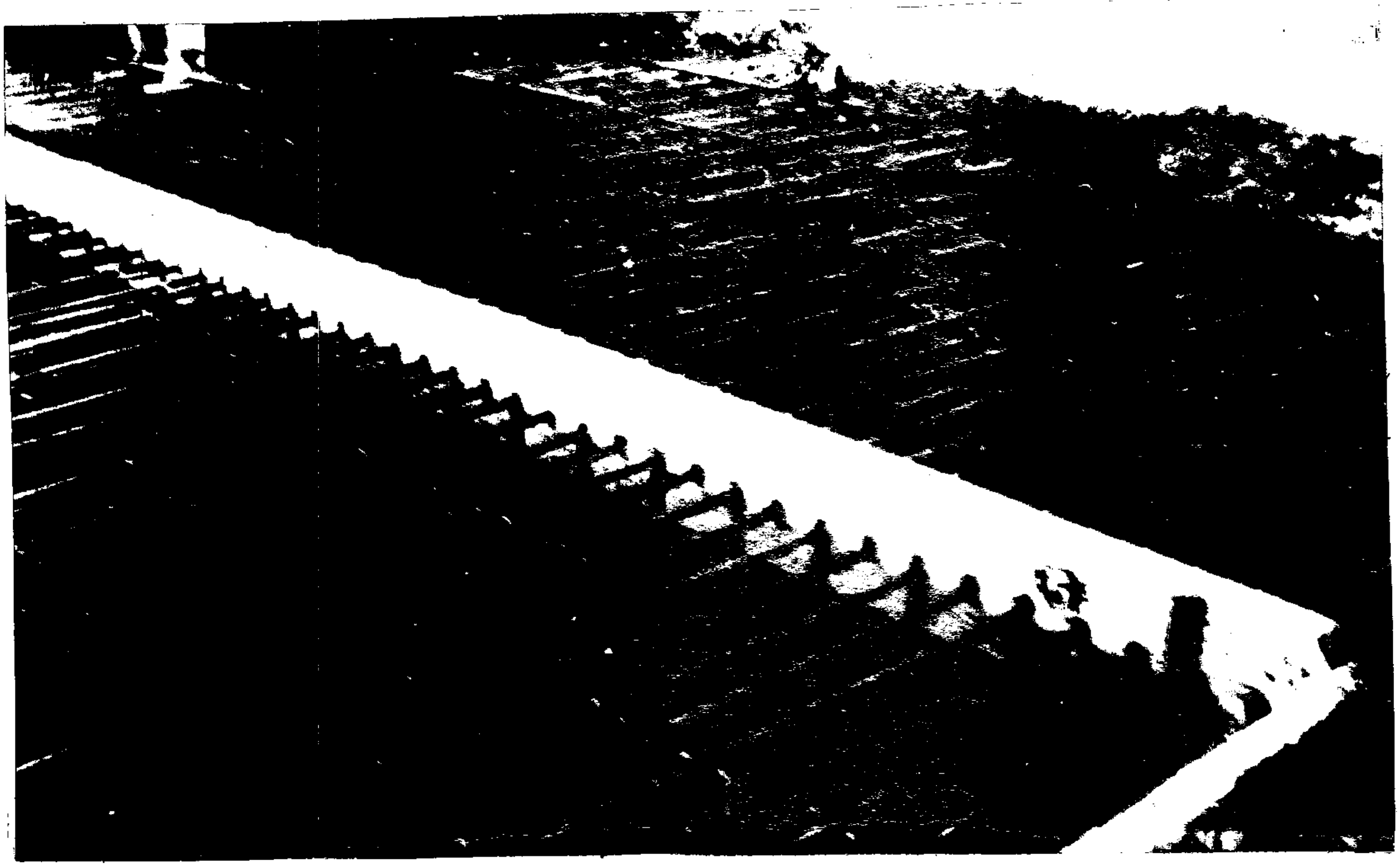


Figure 14. Header board with continuous and supplemental deformed bar reinforcement.

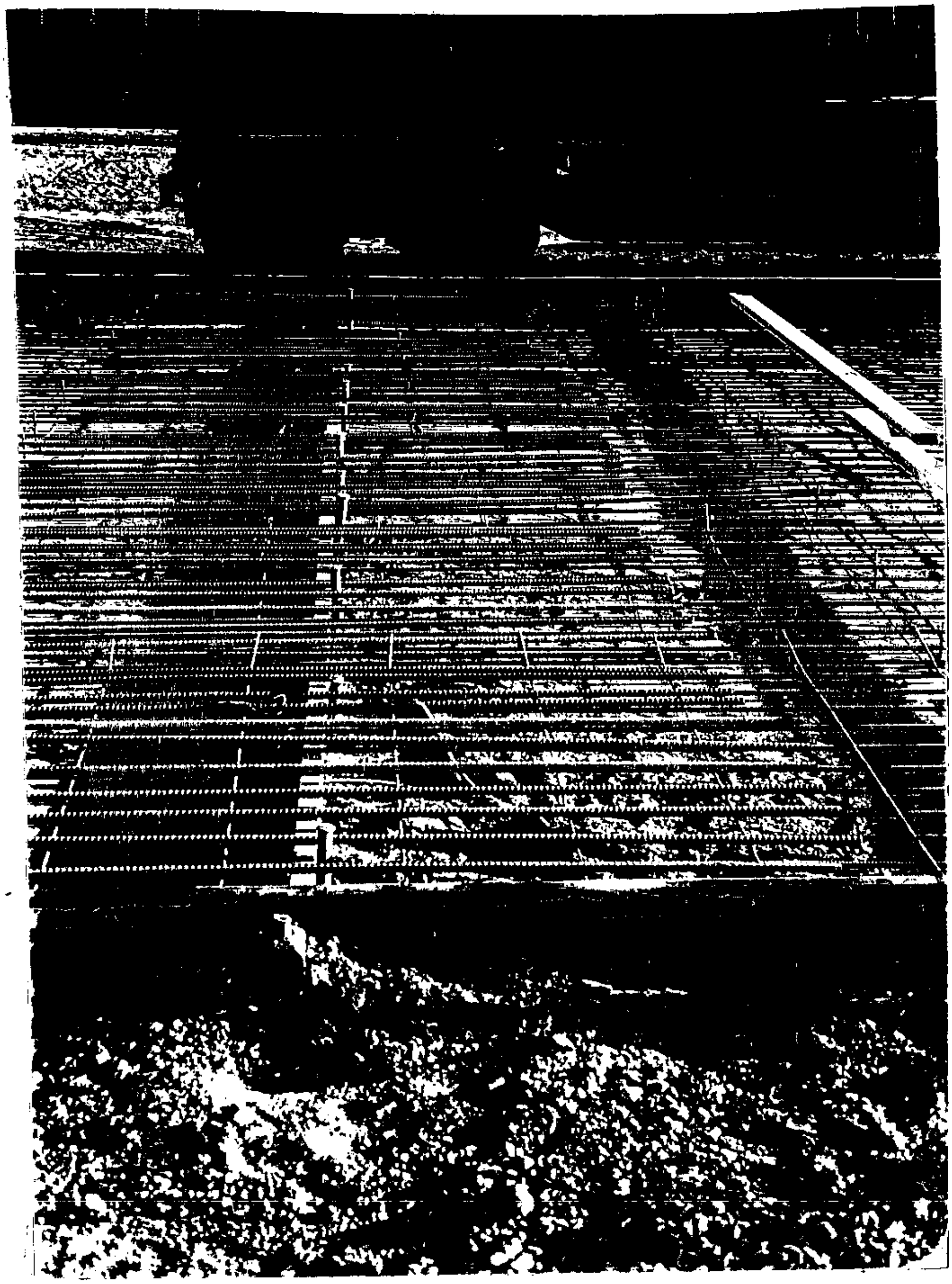


Figure 15. Header board with continuous deformed wire fabric and supplemental deformed bars.

adequate load transfer. For the experimental pavements the reinforcement was doubled by placing 6-foot bars, of the same size as the longitudinal reinforcement, between the main reinforcing bars. Then, each day before paving resumes, the header board is removed; plastic concrete is deposited directly against the hardened concrete and is vibrated by hand to eliminate voids. Since constructing the experimental pavements, experience has shown that the shear transfer can be maintained adequately across construction joints with fewer supplementary bars. Now the specifications require that the number of supplementary deformed bars shall be such as to increase the area of steel through the joint by at least one third as shown on the plans. From 1968 to 1973, the specifications called for bars 3'-0" in length across the joints rather than the 6'-0" bars used in the experimental pavements. However, because of cracks forming in the pavement near the ends of the 3'-0" bars, the specifications were revised in 1973 to return to the use of bars 6'-0" in length.

Longitudinal center joints were cut 1/8 inch wide and 2 inches deep with a concrete saw, and were filled with sealant in both the continuously and the conventionally reinforced concrete pavements. The specifications permitted the joints to be sealed with either hot-poured sealer meeting the requirements of the tentative specifications for concrete joint sealer, hot-poured elastic type, ASTM Designation: D1190-52T or a cold-applied, ready-mixed concrete joint-sealing compound meeting the requirements of the Standard Specifications. The hot-poured elastic material was most commonly used for sealing the sawed joints of the experimental pavements. In later projects, the specifications permitted the contractor to form the longitudinal joint by inserting a continuous polyethylene strip in the fresh concrete in lieu of sawing. The strip of polyethylene sheeting had a minimum thickness of 10 mils and a minimum width of 2 inches but not less than one fourth the total thickness of the pavement being placed.

All transverse contraction joints in conventional control pavements were sawed and sealed similarly to longitudinal joints explained above.

The ends of CRC pavements adjoining existing pavements and bridge approach slabs were partially restrained from moving by anchor lugs constructed to prevent expansive forces from buckling the pavements and damaging the bridge abutments. The anchor lugs varied in number and spacing at different locations. Provisions for some movement were made by constructing expansion joints between the lug areas of the CRC pavement and the abutting pavements. Where the CRC adjoins standard pavement, three 3/4-inch preformed, bituminous fiber, doweled expansion joints spaced at 50-foot centers were provided between the lug area and the standard pavement. Five such joints were provided at locations where end anchorage of the CRC adjoins a bridge approach pavement.

At the joints a wire basket was used to position the dowel bars and to maintain the 3/4-inch preformed bituminous filler in a vertical position. After the last finishing machine passed the joint, the protective steel cap was removed, and the concrete was edged. Finally, the surface at the joint was checked with a 10-foot straightedge to see that no bump or depression had been created during edging.

For the jointed 10-inch pavement, the standard 4-inch premolded expansion joint filler was used to prevent encroachment of pavement at the bridge abutments.

PAVEMENT FAILURES

The amount of steel and length of lap specified in Illinois appear adequate for controlling the width of cracks in CRC pavements. At a few places where excessive crack widths have been found, localized pavement failures have been traced to construction deficiencies consisting of either a total absence of longitudinal steel or insufficient lap. Pavement failures also have been associated with inadequate consolidation of the concrete at construction joints.

Shortly following the completion of one project, it became evident that a crack was growing unusually wide. Within 12 days after paving, the width of this crack was 1/8 inch (Figure 16). After the first winter, the width of the crack had grown from 1/4 inch to 1 inch (Figure 17). Exposing the reinforcement while repairing the pavement revealed a gap in the reinforcement within the area of the crack.

A typical pattern of another failure on the same project is shown in Figure 18. The upper right hand corner insert is a view of the same failure after removing the concrete. The failure occurred across the entire width of the pavement, forming several open cracks which followed the staggered lap pattern of the deformed welded fabric. At this particular place each of the six sheets of reinforcement fabric extending across the pavement width had either an insufficient length of lap or a gap in the steel. Similar localized failures were observed at eight other places in this project soon after the pavement was completed.

In this project the reinforcement fabric was placed on the full-depth concrete and was depressed vertically into position by a mechanical depressor. Tying at laps was not required. Most of the failures occurred at construction joints where the steel extending through the header board was supported by chairs on the subgrade, and the ends of the steel reinforcement were not properly referenced prior to placing the concrete and reinforcement at the beginning of a new pour.

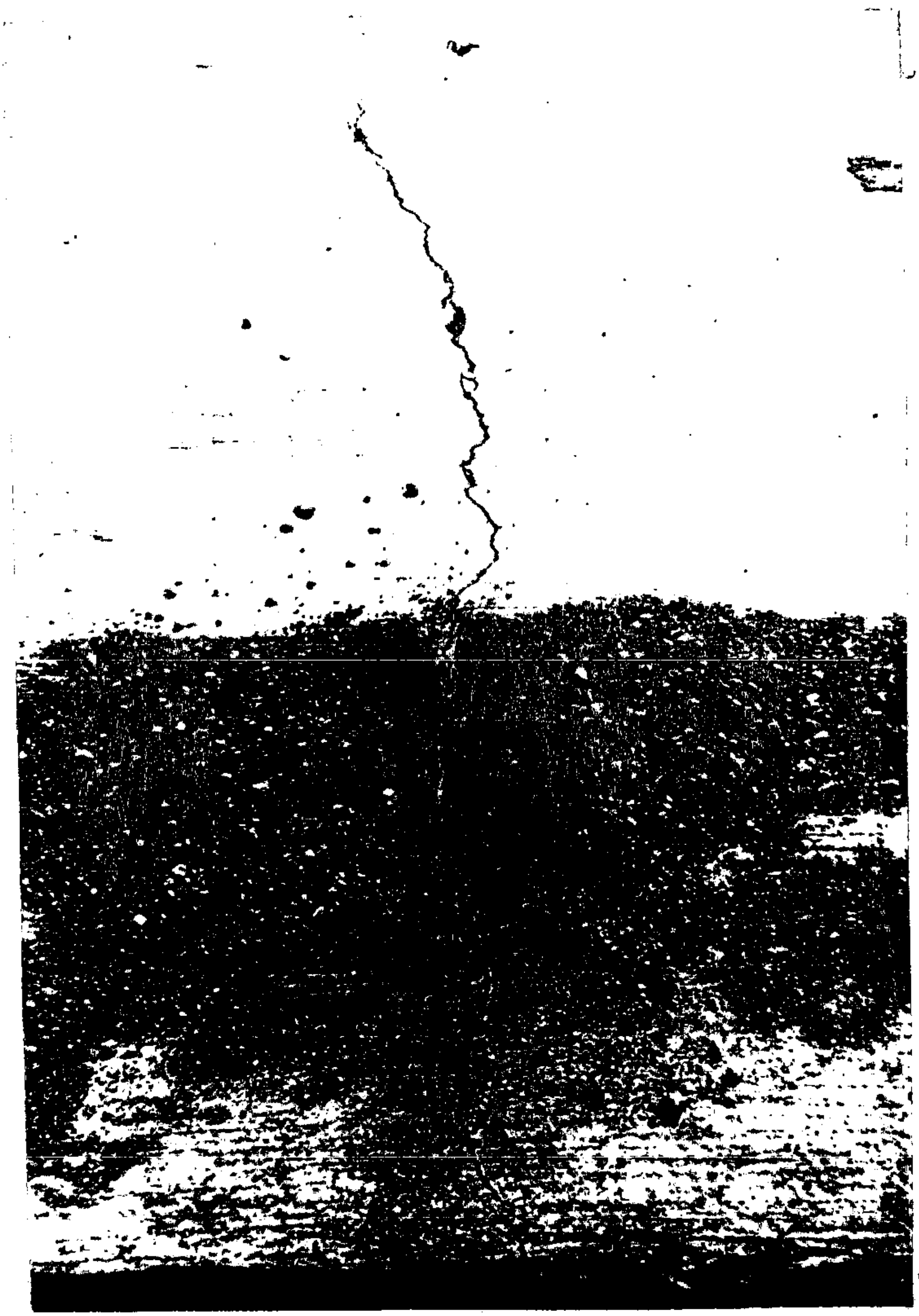


Figure 16. View of crack - 12 days after paving.

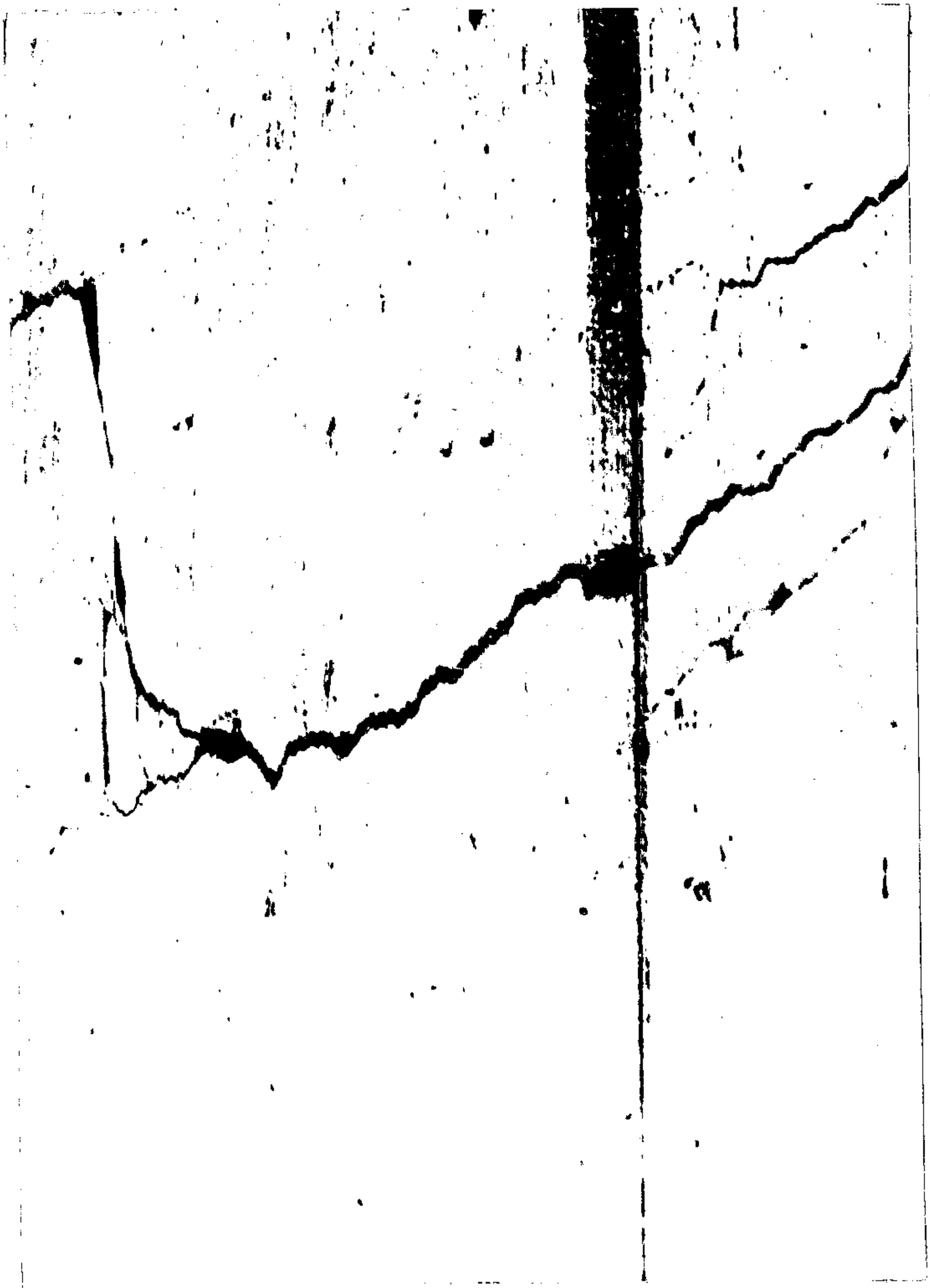


Figure 17. View of crack - after first winter.

Figure 18. Failure at lap of longitudinal reinforcement.

Without a reference for determining where the ends of the previously embedded reinforcement were located, it was difficult to insure proper lapping of the reinforcement being subsequently placed. As a result of these experiences, the specifications now require all lapped reinforcement sheets to be securely tied both transversely and longitudinally, regardless of the method of placement.

A typical failure resulting from inadequate consolidation of the concrete at construction joints is shown in Figure 19. Cores removed from the failed area are shown in the insert of the figure. The core shown on the right, which was taken at the face of the joint, shows a lack of consolidation around and below the longitudinal bar, but the core to the left, which was taken two feet ahead of the right core in the direction of paving, shows that the concrete two feet away from the construction joint was reasonably well consolidated except for a small void at the bottom of the pavement.

A majority of the failures in CRC pavements have been occurring at construction joints. These failures at the joints can be primarily attributed to inadequate consolidation of the concrete adjacent to the joints. Problems of this nature became even more pronounced with the adoption of the slipform paver because of difficulties encountered in attaining adequate consolidation during the start and end of daily paving operations. To correct this situation, the specifications were revised to call for hand vibration to extend for 10 feet on each side of the joint for the full width of the pavement. Prior to this revision, the specifications required that hand vibration extend only along the length of the joint.

Two other factors affecting the behavior of CRC joints have resulted from the use of large central mixing plants and the adoption of slipform paving.

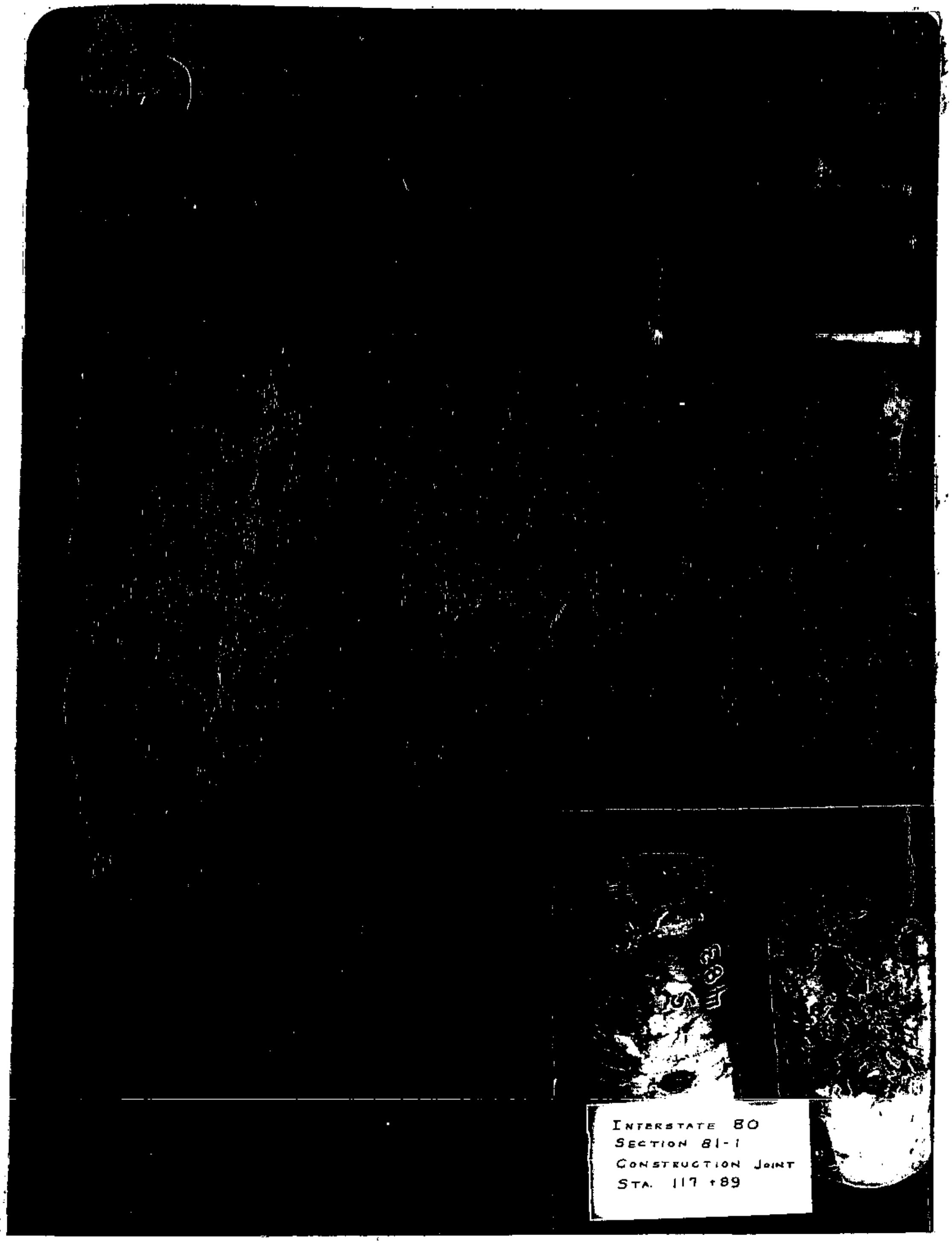


Figure 19. Failure at construction joint.

First, use of the large mixers has resulted in a loss of mortar from the first one or two batches each day due to mortar clinging to the inside of the mixer and the haul truck agitators. This problem was surmounted by revising the specifications to require that the mortar content of the first 10 cu yds or two batches, whichever is greater, that is to be placed adjacent to the previously formed joint shall be increased by the addition of cement and fine aggregate at the rates of 50 and 120 lbs per cu yd, respectively. This allows mortar to coat the mixers and trucks, and also gives additional strength to the concrete immediately beyond the joint.

Second, the foam and excess mortar that tends to accumulate on the surface of the head of concrete carried in front of slipform pavers during paving operations were sometimes incorporated into the pavement at the construction joint placed at the end of a day's paving. This resulted in inferior quality concrete and early failure at the evening side of the joint. The specifications were revised to specifically require the contractor to waste this material and not place it in the pavement.

In some cases when temperatures fluctuate widely, movement of the existing slab is stabilized by covering the last 100 feet to 300 feet of pavement with water, wet sand, or wet straw.

PAVEMENT REPAIRS

Patches in CRC pavement are very sensitive to recurring failures, so special precautions need to be taken when making repairs. Examples of two failures resulting from improper patching techniques are shown in Figures 20 and 21. These patches failed within a few days after making the repairs. In Figure 20, a large opening occurred between the patch and the existing pvement because the lap between

Figure 20. Patch failure due to insufficient lap between new and the existing reinforcement.

Figure 21. Patch failure due to bend in the reinforcement.

the new and the existing reinforcement was insufficient. The patch in Figure 21 not only opened up at the joint but also raised above the existing pavement. In this case the patch failed because the reinforcement was bent up out of the way while removing the old concrete and then bent back down forming an "S" shape at the face of the existing concrete. In fact, almost all of the existing steel was found near the bottom of the patch rather than in the same plane as the new steel. The thin portion of new concrete below the "S" shape in the old steel had fractured, and the unusual bend in the reinforcement created an eccentric loading along the longitudinal bar which caused the patch to raise above the existing concrete. Furthermore, both original patches, which were short, only 6 feet long, have been replaced with at least 10-foot-long patches that are now behaving satisfactorily.

A similar failure also has occurred at a construction joint between a new and an old pavement as shown in Figure 22. During this investigation, it was found that the steel on the raised side (new concrete) of the construction joint had a sharp downward bend. It is believed that the bend in the reinforcement did not maintain the stress axis in the same horizontal plane during expansion and contraction of the slab, and therefore ruptured the concrete along the reinforcement path.

Procedures established for repairing construction deficiencies required that patches be at least 10 feet long and one lane wide. A minimum lap of 36 inches with the existing steel also is recommended. This lap is achieved by making two saw cuts at least 40 inches apart at each end of the patch. The outer saw cut at the edge of the patch is limited to a depth that does not damage the existing steel. The inner saw cut, at a distance of 40 inches from the outside edge of the patch, is made through the reinforcing steel for full-depth

Figure 22. Construction joint failure due to bend in the reinforcement.

removal of the concrete and reinforcement. The ends of the patch should be at least 18 inches from a transverse crack and at least 10 feet from a construction joint.

Care must be exercised to avoid damaging the existing steel that is extended into the patch for lapping the new reinforcement. If less than 10 percent of the existing lap steel is damaged, the reinforcement may be repaired by welding. However, no welding is permitted between the existing steel and the new steel. If more than 10 percent of the existing steel is damaged within the lap area, the patch should be lengthened to provide the minimum 36-inch lap.

The reinforcement extending from the existing pavement in the lap area should not be raised above the pavement surface at any time during or after concrete removal. The new reinforcement should be supported by chairs placed at the proper elevation and should be securely tied in place, with particular emphasis on maintaining the existing and new reinforcement at the same horizontal plane.

At times when the temperature fluctuates widely, the existing pavement should be stabilized by wetting as previously described.

Bending of the reinforcement should also be avoided at locations where construction of the pavement ends under one contract and begins under another contract at a later date. At these locations, the steel was formerly bent upward to allow reworking the subbase prior to continuing construction. The need to rework the subbase near the end of the completed slab was eliminated by constructing a 10-foot sleeper slab extending four feet underneath the finished pavement. Until construction is resumed, the steel extending five feet from the end of the finished pavement is supported by wooden blocks resting on top of the 6-foot exposed portion of the sleeper slab.

DISCUSSION

The development of mechanical means for economical and efficient placement of the reinforcement, whether deformed bars or pavement fabric, has been one of the principal objectives of this research.

As previously mentioned, deformed bar reinforcement was used throughout the projects in Champaign County and in Fayette County, and deformed wire fabric was used throughout the Rock Island County and the Williamson County projects. The experimental pavements in Sangamon County and in Knox County were constructed using both deformed bars and fabric in alternate sections.

Of the six contractors who were involved with constructing the pavements, three had developed a mechanical method for depressing the fabric reinforcement in full-depth concrete, but only one contractor used mechanical means for placing and depressing the loose bar reinforcement. In the two remaining cases, the contractors chose to preset and tie the reinforcement in place before placing the concrete.

The development of a quick and efficient method of mechanically placing the reinforcement is necessary for reducing the cost of pavement construction. Regardless of the method used, however, the final position of the reinforcement embedded in the concrete must be within tolerable limits. The special provisions for the experimental projects required the reinforcement to be placed within $\pm \frac{1}{2}$ inch of the plan dimensions.

During the spring of 1970, several cores were removed from the experimental pavements to study the condition of the longitudinal reinforcement.[4/] This study also provided an opportunity to investigate the actual depth of the reinforcement below the pavement surface. The summary of steel depth measurements by method of placement is reported in Table 6.

TABLE 6

SUMMARY OF STEEL DEPTH MEASUREMENTS FROM CORES

(Experimental Pavements)

Method of Placement	Total Cores	Cores with Steel Exceeding ± 1/2 in. Design Depth	
		No. of Cores	Percent of Total
Mechanically Placed & Depressed (Bars)	18	4	22
Hand Placed & Mechanically Depressed (Fabric)			
Ski Type	28	16	57
Grid Type	12	4	33
Hand Placed on Chairs (Bars and Fabric)	82	19	23

Of 140 cores removed for study, 18 were from pavements with the loose bar reinforcement placed and depressed by mechanical means, 28 cores were from pavements with the fabric depressed by a ski-type depressor, 12 cores were from pavements with the fabric depressed by an independent grid-depressor machine, and 82 cores were from pavements with either deformed bar or fabric reinforcement tied-in-place on chairs.

The summary in Table 6 indicates that bars can be positioned mechanically with about the same accuracy as bars and fabric placed on chairs. Fabric depressed vertically by a grid frame was slightly less accurate than this type of reinforcement placed on chairs, and fabric depressed by a ski-type sled depressor is the least accurate method of positioning pavement fabric. The ski method requires frequent inspection to insure that the equipment is operating satisfactorily. If the sled is not properly adjusted, there is a tendency for the machine to drag and to force the reinforcement out of position. The findings of this study indicate that use of the ski-type sled depressor should be avoided. Also, it can be seen from Table 6 that a marked percentage of the cores had steel depths outside the $\pm$ ½-inch tolerance regardless of the method of placement.

Initially, plans for CRC pavements in Illinois, other than the experimental pavements, called for reinforcement to be placed 3 inches from the top of the slab with a specified tolerance of $\pm$ ½ inch. Measurements from 833 cores taken from 17 projects completed in 1970 indicate that 304 cores, or 36 percent, contained steel exceeding the 3 $\pm$ ½-inch tolerance, 219 cores, or 26 percent, contained steel exceeding limits of 3 $\pm$ 3/4 inch, and 81 cores, or 10 percent, contained steel exceeding a 3 $\pm$ 1-inch tolerance. This information demonstrates that the $\pm$ ½-inch tolerance was too tight, and that a tolerance of $\pm$ 1 inch is more realistic. Illinois specifications were revised in 1968 to require that the position of the reinforcement in the finished pavement be within $\pm$ 1 inch of plan dimensions both horizontally and vertically.

In 1973, at the insistence of FHWA, the specifications were again revised to require the longitudinal reinforcement to be not lower than mid-depth of the slab and at least 2½ inches below the top surface of the slab. This current specification has been interpreted to mean that the top of the longitudinal steel must be 2½ inches below the top of the slab, and the bottom of the longitudinal steel must be not lower than mid-depth of the slab. The $\pm$ 1-inch tolerance for horizontal position was retained.

The maximum permissible depth of steel placement in the latest specification revision is based on findings from studies of the behavior of continuously reinforced concrete pavement. The minimum requirement of 2½ inches of concrete cover over the steel apparently has come from studies of corrosion of steel in concrete bridge decks causing cracking and spalling of the concrete, a phenomenon which has not been observed in Illinois CRC pavements except at a few isolated locations where the concrete cover was less than one inch.

The tolerances in steel placement are more restrictive than before and are beyond what our field measurements have demonstrated can be expected to be obtained with present methods of steel placement employed in construction.

Examination of 364 cores taken from 8-inch CRC pavement at 11 projects completed in 1975 indicates that 282 cores, or 77 percent, contained steel which was placed outside the specified limits. A similar examination of 100 cores from 9-inch CRCP at six projects indicated that 64 percent of the cores contained steel located outside the specified limits.

A further revision in the specification to place the reinforcement at a depth of 3 inches $\pm$ 1 inch for all pavement slabs of 8 inches or less in thickness, and 3½ inches ± 1 inch for all pavement slabs greater than 8 inches in thickness, was approved for use on a trial basis during the 1977 construction season. The results are to be reviewed at the end of the construction season to determine if any problems are being encountered when the reinforcement is placed in this manner.

Since constructing the experimental pavements, several innovations in paving equipment have been developed that have substantially reduced paving cost. In 1964, Special Provisions that permitted contractors to place PCC pavements without side forms were included in several contracts. During the summer that year, the first pavement constructed in Illinois with a slipform paver was built as part of FA Route 9 in Warren County. Other contractors were quick to recognize the advantages associated with slipform pavers and began to equip themselves for this type of pavement construction. Consequently, a growth in the use of slipform paving had occurred between 1964 and 1969. Within this period of transition a change also was made from the standard, jointed pavement to CRC pavement for all interstate and most primary highways.

During the transition from side form paving to slipform paving, new developments in the design of equipment were required for mechanically placing the reinforcement. The elimination of the transverse reinforcement, except for short tie bars across the longitudinal center joint, was tried by Iowa in 1967 and later by Wisconsin in 1969. By eliminating transverse bars, placement of the reinforcement was simplified by feeding the loose longitudinal bars through a series of tubes that held each bar in position while the concrete was placed and vibrated around the bars. The system of tubes was either a separate machine operating immediately in front of the paving train or a rack connected directly to the front end of the slipform paver.

After at least three years of service, CRC pavements without transverse bars in Iowa and in Wisconsin were behaving similarly to those CRC pavements in Illinois containing transverse bars. Apparently omitting transverse bars had little or no effect on the performance of CRC pavements. Because of the success of previous experience by other states, Illinois, in 1970, adopted this method as an alternative for placing pavement reinforcement. From the standpoint of economy, this method of construction has become very popular. During 1972 and 1973, over one half of the contractors in Illinois were eliminating transverse reinforcement and placing only loose longitudinal deformed bars with a system of tubes.

A more recent innovation used in conjunction with the tube device is a "lawnmower-type" reel developed by a contractor to insure that the required depth of the reinforcement is maintained below the pavement surface. This device was first used on a project constructed south of Springfield as part of Interstate 55. The paving train for the project consisted of a CMI placer-spreader with a tube rack mounted between the front tracks, a CMI paver with the "lawnmower-type" reel attached to the front of the paver, and a CMI tube finisher. The amount of labor involved with the project was minimal, and substantially cut paving costs. The longitudinal reinforcement for the project consisted of 50 No. 5 bars, 60 feet long, that were placed directly on the subbase and were fed through the tube rack attached to the spreader. The bars were made continuous by splicing the ends with ties on the subbase ahead of the paving train so as not to interrupt the paving operation. A special dowel inserter on the back of the spreader was used to depress tie bars across the center joint. The "lawnmower-type" reel in front of the paver was set to cut

3 inches into the freshly placed concrete to insure that the reinforcement was at least 2½ inches below the surface of the pavement.

The different mechanized methods used in constructing the experimental pavements with side forms became obsolete almost as soon as they were developed, because of the introduction of the slipform paver. It is essential for engineers, contractors, and equipment manufacturers to continue to improve pavement designs, to find new paving materials, and to develop new paving equipment that can cut paving costs, especially in times when both labor and materials are continually rising.

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